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INTEGRATED MODULE FOR SOLID OXIDE FUEL CELL SYSTEMS USING STEAM OR AUTOTHERMAL REFORMING OF HYDROCARBON FUELS

FIELD OF THE INVENTION

The present invention relates to an integrated module for solid oxide fuel cell (SOFC) systems comprising a prereformer, an afterburner and a heat exchanger.

BACKGROUND OF THE INVENTION

As the majority of current remote power customers use natural gas or propane, these are obvious choices for SOFC fuel in remote power generation systems. As well, many other applications exist for fuel cell systems such as home cogeneration and automotive uses. SOFC's have the advantage of easily being able to use hydrocarbon fuels through fuel processing methods including steam reforming, partial oxidation and autothermal reforming. As fuel processing of hydrocarbons occurs at or near SOFC operating temperatures, thermal integration of both the fuel processor and stack is desired.

Steam reforming is a method that realizes a high overall system efficiency and provides the stack with a hydrogen-rich fuel. Therefore, it is desirable to provide a SOFC system which provides steam reforming of a hydrocarbon fuel.

It would be advantageous if a module for use with a SOFC system would effectively interface SOFC stacks with low temperature heat exchangers and in so doing also accomplish the following: 1) completely oxidize the fuel remaining in the SOFC stack anode exhaust gas using the stack cathode exhaust gas or other air, and 2) directly utilizes the heat produced by oxidation of the anode exhaust gases to preheat and pre-reform all

or substantially all of the hydrocarbon/water fuel mixture being fed to the SOFC stack, using a suitable catalyst, and 3) also further directly heat the incoming (to SOFC stack) cathode air.

SUMMARY OF THE INVENTION

An integrated module for use in a solid oxide fuel cell system is disclosed which combines several functions into one unit. In one embodiment, the integrated module oxidizes the fuel cell stack anode exhaust using the stack cathode exhaust or other air, preheats and prereforms (processes a percentage of, or completely) the incoming hydrocarbon/water mixture using a suitable catalyst to provide a hydrogen and carbon monoxide rich stream for the fuel cell anode, and also further heats the incoming cathode air.

According to a broad aspect of the present invention, there is provided a module that is part of the fuel cell system, the module comprising a fuel processor, an afterburner including an igniter and a heat exchanger. The afterburner burns the unused fuel in the SOFC stack exhaust. The heat produced by the afterburner is exchanged by the heat exchanger to preheat the air stream into the SOFC stack. The fuel stream is also preheated and prereformed in the fuel processor which also uses heat from the afterburner. The fuel processor comprises an effective catalyst and a water source so that steam reformation of the hydrocarbon fuel may take place as it passes through the fuel processor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic of a process of the present invention.

Figure 2 is a schematic depiction of an apparatus of the present invention.

DETAILED DESCRIPTION

In one embodiment, the exhausts from the fuel cell stack passes through the centre of the module in a generally tubular conduit, which contains the igniter as an insert in a portion of the module. This tubular conduit is the afterburner portion of the module. The igniter is also tubular, and is used for igniting the afterburner on cold system starts. The igniter is only in operation to initiate combustion, and then can be turned off. In one embodiment, a fuel burner tube is contained in the afterburner to control mixing of anode and cathode exhausts. Other combustion technologies such as sintered metal, porous ceramic and nozzles can also be utilized. Controlled mixing is required during normal operation as these gases auto-ignite at the afterburner operating temperatures. The burner tube contains small holes for the fuel gas mixture to escape, and also acts as a burner support. At any time when the stacks are not producing electrical power, the afterburner is the sole source of heat to bring the fuel cell stack (and thus complete system due to its thermal integration) up to, and maintain operating temperature. However, additional system burners can be added to provide a faster warm up from a cold start, or provide more rapid changes from one operating temperature to another. In normal continuous operation the burner consumes hydrogen, carbon monoxide and any hydrocarbon fuel not consumed by the fuel cell. In the current embodiment, during heat up, standby and normal operation, the mixture fed through the afterburner is the exhaust from the fuel cell stacks. When the fuel processor and stack are in a temperature range when fuel reforming is possible, such as in normal operation, hydrogen and carbon monoxide are the major fuel species found in the fuel (anode exhaust to afterburner) together with a small amount of raw fuel such as methane. The burner has been optimised for this mixture, while still being able to burn natural gas (or other raw fuel) and air mixtures for cold starts.

Surrounding the afterburner are the other portions of the integrated module. In one embodiment, a high temperature air heat exchanger encircles the afterburner, and the heat exchanger transfers the heat energy from the afterburner and fuel cell exhausts to the incoming air and fuel/water mixture (which is to be heated further, and processed in the

module). An associated piece of equipment included by way of reference is a low temperature heat exchanger(s) that preheats the incoming raw air and fuel. The preheating of the air and fuel is done in stages so as to avoid large thermal stresses upon the heat exchangers.

The fuel processor, or prereformer, takes a natural gas/water mixture, or another hydrocarbon/water mixture, as its feed stream, and passes it over a suitable steam reforming catalyst such as a nickel/alumina catalyst. The hydrocarbon and steam react in an endothermic reaction to produce hydrogen and carbon monoxide. The thermal energy released from the afterburner is used to drive this endothermic reaction. In one embodiment, the catalyst is in pellet form contained within the fuel processor chamber.

As a by-product of the electrochemical reaction to generate electricity in the fuel cells, hydrogen and carbon monoxide formed in the fuel processor are converted to water and CO_2. The water is in vapour form as it exhausts from the fuel cell stack due to the high temperature and passes through the afterburner as superheated steam. In the afterburner, complete oxidation of all fuel species occurs, resulting in a high temperature exhaust stream only containing water vapour, carbon dioxide and nitrogen, and possibly excess oxygen. The afterburner feed gas (anode and cathode stack exhausts combined) is preferably fuel lean to stoichiometric to reduce the possibility of unoxidized fuel leaving the system. Typical air stoichiometries for the combustion reaction in the afterburner are about 1.0 to about 2.5. After combustion, the afterburner combustion products are exposed to the high temperature heat exchanger in the integrated module, and the low temperature heat exchanger located outside integrated module, where the combustion products give up a substantial portion of their heat to the incoming fuel and air flows, and then is exhausted to the atmosphere. As for the fuel stream, water is injected in a preheated hydrocarbon fuel gas prior to it entering into the prereformer. In another embodiment, air can also be added to the hydrocarbon/water mixture passing through the fuel processor portion of the integrated module to realize autothermal reforming. When in the fuel processor, the hydrocarbon fuel / water mixture reacts, converting the incoming gases to a hydrogen and carbon monoxide rich stream when heat is supplied from the

afterburner. Normally this is done with a steam to carbon ratio of 1.3:1 to 3.0:1.0 to ensure that solid carbon is not formed when the hydrocarbon / water mixture is heated. After conversion by steam reforming, the hot gas composition is generally dictated by the gas temperature and related thermodynamic gas equilibrium. In one embodiment, the invention is concentric about the core afterburner combustion tube, although other geometries such as a planar module and multiple coils through the afterburner portion of the module are possible.

In SOFC fuel cell systems, thermal integration is desired. The described integrated module offers a unique functional thermal system during heatup, normal operation, and transients. During transients of the power load on the fuel cell stack, and changes in air and fuel flow rates, the integrated module offers excellent response. For instance, if the stack electrical load is decreased, the heat generated in the stack (the waste heat portion of the fuel cell reaction) also decreases. However, the afterburner in the integrated module responds automatically due to the change in incoming fuel composition, and increases in temperature. Thus, increasing the temperature, and amount of preheating of the air and fuel to the stack, thus maintaining a relatively constant stack temperature. Other functional advantages of this integrated module arrangement should be apparent to those skilled in the art.

In the future, many suggest that hydrogen will be the fuel of choice for fuel cell systems. This component is also very functional using hydrogen as fuel. The catalyst contained in the fuel processor may be removed, to let it act only as a hydrogen preheater. In such hydrogen systems, the requirement for water, or air, to be added to the fuel stream is likely, but will not necessarily have to be removed.